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The Use of Unmanned Aerial Vehicles by Urban Search and Rescue Groups

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Abstract

In the case of natural or man-made disaster, the top priority of urban search and rescue (USAR) groups is to localise the victim as quickly as possible. Even minutes might play a crucial role in the victim's survival. A number of standard operating procedures may be applied to achieve best performance. Rescue dogs are trained to search for alive victims; special inspection cameras are used, before heavy equipment is being implemented. To improve the effectiveness of USAR group operations, innovative technologies might be implemented. The most recent solution is currently designed in MOBNET project, founded by EU under the Horizon 2020 programme. The scope of the project is to combine both cellular technology and early Galileo services to localise the smartphones of potential victims. Integration tests give some promising outcomes. The following chapter looks at typical applications, real needs of public services as well as the performance of the novel system.

Keywords: UAVs, S&R groups, rescue, EGNSS, GPS

1. Introduction

Unmanned aerial vehicles (UAVs), colloquially called drones, are currently the most innovative element used in support of various industrial sectors. The development rate of this industrial sector is catching up with expansion of the cellular or IT sector.

UAVs may be used in various types of activities of the public and private sector, namely:

- Public administration: border guards or services providing assistance after disasters or military services
- Enterprises: monitoring and maintenance of buildings, power companies, construction sites, agricultural facilities, farms, geological discoveries or aerial photographs
- Clients: deliveries of goods, advertising, guided trips and games

To put shortly each UAV is assumed to consist of two main components—the machine as such and the terrestrial control station or a mobile one. On the other hand, the drone comprises a system controlled in real time, control software, interface module to simplify the exchange of data, sensors connected with the software and the avionics. Optionally it may also have an arm control system (if equipped with weapons) or an autopilot. The terrestrial control station comprises control software, interface modules and the controlling person.

Such public services, for example, the fire service, are executing their operations in many fields connected with prevention, rescuing and civil protection. This is a great advancement as compared to the scope of obligations dating a few decades back. The dynamics of those changes has required (and still requires) continuous staff advancement, modernisation of the equipment base and revising adopted solutions with respect to rescue actions.

Given a certain natural division, selected fire service units are specialised in specific domains: technical rescuing, high rescuing, chemical and ecological rescuing, etc. There is also an area connected with elimination of consequences of events of a greater magnitude. Search and rescue groups may go into the state of combat readiness in a few dozen of hours. If means and resources of local communities are insufficient to handle the disaster, the state can formally apply for assistance by launching, for example, a heavy urban search and rescue (HUSAR) group, which has the most extensive scope of competencies and a developed equipment base. The activity of the group may be proven by the most recent dispatches of the Polish HUSAR group:

Earthquake in Nepal (May 2015)

Polish rescuers along with 12 dogs trained to search for survivors and 6 tonnes of equipment were used to search Nepal devastated by the earthquake. The action lasted 11 days. Almost 9000 persons have lost their lives during this incident [1]. For each urban search and rescue group that reached the scene, a particular area to be searched has been assigned. Taking into consideration the size of the disaster, the whole operations required immensely well-coordinated organisation. In fact, the survival of the victims was depending on hours between the incident and the USAR teams to localise the victim. In total, not many alive victims has been found. It is clear that the most valuable resource in case of man-made or natural disaster, where many victims need to be found and rescued, is time.

Earthquake in Haiti (January 2010)

An earthquake of 7° in the Richter scale caused a few hundred thousand victims. A group of Polish rescuers comprising 54 officers and 10 sniffer dogs arrived in Port-Au-Prince. High

temperatures were not supportive for work of the rescuers [2]. As there were many USAR teams invited to support the operations, it was a difficult coordination task for local authorities. With extraordinary damages to the infrastructure, it caused significant delays in reaching some areas, especially distant, as the accessibility was limited.

Previously described disasters took place a couple of years ago. In both cases, but also in smaller incidents of regional/national range, the rescuers were fighting with the toughest enemy—the time. It is impossible to improve the deployment time; as the equipment must be prepared, members of USAR team must gather, and some further organisational arrangements must be made. The time necessary to transport these resources on the scene is also unavoidable. After arrival, reaching the scene might also be difficult, due to the infrastructural damages. That is why every minute after arrival might be crucial for the victims' survival. If we cannot shorten the described above deployment/transportation time, it seems that the most important aspect to be considered is the effectiveness of the search and rescue operations.

Search and rescue action groups are generally considered a certain type of “elite units” in the fire service. They remain in constant readiness, go through training courses lasting several hours and also personally train their rescue dogs that are allowed to participate in the actions once they have passed a special exam. Together with such equipment, as inspection cameras or geophones, this is a highly effective way of searching for surviving victims, e.g. in the cited earthquakes. Can modern technologies replace those infallible traditional search methods? Absolutely not. Yet quite clearly they may enhance the effectiveness of conducted search actions. UAVs are a good example. At times of universal access to different types of mobile devices, almost every person carries a mobile phone. This could be used for search needs. A victim lying under the rubble may have a cell phone which would remain switched on until the battery becomes empty, provided it has not become damaged during the event as such. The telephone will try getting a connection with the closest base station. The question is, does having an own base station allow supporting rescue actions?

The response to this question will be presented in subsequent subchapters. It should be emphasised that although this chapter focuses primarily on the use of UAVs in the operation of search and rescue groups, the proposed solutions will easily facilitate implementation in the activity in other public services, such as protecting facilities of particular importance, control of state borders, and assuring security during mass events.

2. Identification of needs

2.1. S&R operations: typical activities

Actions of search and rescue groups are implemented according to strictly defined procedures, which may be basically divided into two categories: local (domestic) and international ones (e.g. under UN-INASARAG). Those procedures regulate among others such aspects as operating readiness and equipping and also regulate among others such aspects as operating

readiness, equipping and the size of groups. In general terms, the operation performed by groups during an action may be divided into four basic phases [1]:

1. Mobilisation
2. Action
3. Demobilisation
4. End of mission

The second phase (action), which takes place on the area afflicted by the disaster, requires coordination of actions of all specialised groups present on the spot. To be able to provide effective help to victims, rescue activities performed on the disaster scene are divided into five consequent stages:

- a. Reconnaissance, including identification of hazards and determination of the size of the hazard zone
- b. Initial determination of the number of missing persons
- c. Securing, including lighting of the scene
- d. Finding persons present in inaccessible places
- e. Reaching victims with the use of available equipment, granting competent first aid, evacuation of victims and persons at risk from the hazard zone

Each stage should be properly planned and implemented. The first step to be executed on the scene is among others the determination of the size of hazard zone. Given the nature of the activities, in many cases this stage may not be executed quickly or accurately. During large-scale building disasters, caused in particular by earthquakes, the size of hazard zones is considerable, and as an effect, reaching and identifying all areas requiring intervention, for example, owing to cutting off of transport routes, as a rule tend to be hindered.

For this reason one of the implementation methods of this task is a surface search, in other words an accelerated one. It consists in a rapid extensive surface search of the area afflicted by the disaster in order to find areas characterised by high survivability level, like persons immobilised by minor rubble. This solution is strictly connected with restrictions concerning the number of rescuers.

It is assumed that this state would remain unchanged, i.e. the number of rescuers on the scene would not be increased, and so to optimise the search process, it is necessary to have increasingly novel solutions deployed.

2.2. Innovations in fire service

Advanced search methods with the use of modern technologies, such as geographic information system (GIS), rescuers' communication and positioning systems, thermal vision, modern off-road vehicles or unmanned aerial vehicles, clearly improve the possibility of effective execution

of a rescue action. Correct and effective search actions may be performed by thorough planning of activities and maximum usage of the available resources and means.

It should be assumed that at present modern solutions adopted by specialised search and rescue groups should comprise the following.

2.2.1. Making use of precise digital maps (GIS) with the GPS technology (or an optional one)

This type of maps may take into consideration all-terrain obstacles and the location of available resources and means, as well as data bases related to potential trends in the behaviour of missing persons, which in combination with local terrain and weather conditions at disposal of professional rescuers from the given region may significantly accelerate making appropriate decisions. Maps should be available at the command stand, both stationary ones and also of the mobile type, to allow handling data received from communication module-based GPS systems (or different ones) and their transfer to the base and to the database serving as the centre of the GIS. Particular elements may be visualised in the system and enable accurate identification of their type by verifying the equipment ID and its current position. The map displays the position of rescuers determined based on a signal sent from radiotelephones with an installed GPS receiver. The effectiveness of this type of solution is nevertheless limited by the necessity of preparing maps prior to the occurrence of the hazard. However during actions performed on the same area, this solutions gains on effectiveness with the number of events occurring on the area under protection. Consequently digital maps should be dedicated to rescue groups protecting the defined area, for example, mountain rescue service [2].

2.2.2. Ground units used in search and rescue actions

The equipping of search and rescue groups that facilitates the process of searching and locating missing persons, as well as their safe evacuation, comprised all types of mechanical vehicles having diverse type of drive equipped with wheels or tracks. Also, in this respect, novel structures are being developed to support rescuers in their actions. Evacuation may be executed also by air with the use of rescue helicopters; nevertheless difficult weather conditions, relatively high usage costs, lack of available landing place or safe handling of the victims and a considerably low number of such equipment units available make it necessary to seek other solutions that would be much cheaper and more resistant to adverse weather conditions and difficult terrain conditions. Such accessories comprise road vehicles or track and wheel vehicles, such as off-road vehicles, quads, all-terrain vehicles or amphibians (**Figure 1**) [4, 5].

2.2.3. Unmanned aerial vehicles (UAVs)

The use of unmanned aerial vehicles is becoming increasingly popular in actions performed by rescue groups. Most frequently used unmanned aerial vehicles are multicopters, which are capable of vertical take-off and hovering, as well as airplanes or motor gliders, which take off from roads or a special catapult. Selecting the appropriate type of UAVs entails certain advantages and drawbacks. The main drawback of multi-propeller airplanes is their available flight time, which as a rule tends to be within the range of 15–60 minutes depending on the battery size. On the other hand, the main advantage of multi-propeller

airplanes is their manoeuvrability, which in combination with their furnishing with a dedicated camera may considerably reduce the impact of terrain conditions with the use of UAV for search activities, and their furnishing with thermal vision cameras allows finding people even after twilight (**Figure 2**). Unmanned aerial vehicles may also be used for drawing up orthophotos or to provide the view of the scene of actions from a close distance.

2.3. A gap for dedicated UAV applications?

The application of modern technologies in rescuing is highly desirable. Search and rescue groups, the specific nature of actions of which is connected with carrying out actions in difficult terrain conditions, have been found to have particular needs. Given the increasingly frequent access to modern technologies, more and more frequently use is being made of geolocation technologies, and the usage of unmanned aerial vehicles in actions, and consequently the combination of both strategies seems to be a natural step in the implementation of those solutions in rescue actions. The MOBNET system is implementing this trend by using cellular phone signals, the GALILEO system, the European navigation system to localise signals with an accuracy of even 10 cm and unmanned aerial vehicles. The rate and accuracy of localising offered by the system, which is made possible thanks to the fact that according to the Digital in 2017 Global Overview Report ca. 66% people worldwide use their mobile phones every day, are aimed at finding a tool to support considerable search and/or rescue actions.



Figure 1. Example of ground units (a) adapted to driving in a complex terrain trailer pulled by Land Rover Defender 110 [3], (b) all-terrain vehicle Swincar [4] and (c) ARGO 8 × 8 amphibious vehicle in a track and wheel version [5].



Figure 2. View from thermal vision camera provided on UAV—looking for missing persons [6].

3. Methods

In response to needs of the market, in the first place of rescue services in the context of enhancing the effectiveness of search actions, an idea was conceived of building an aerial vehicle dedicated to this particular type of activity. As the solution should be best tailored to needs of final users, in the first place, the target groups have been identified. The most important ones of them include the following:

- Superior user: the fire service (search and rescue actions) as a consequence of building disasters, natural calamities, search of missing persons on larger areas and possibly also finding rescuers during diverse types of actions
- Public order services (support during mass events, identification of persons inside a premise)
- Border security services (detection of potential smugglers, persons crossing the border illegally)
- Institutions that control access to specific facilities (protection of critical infrastructure, access control)
- Other services (search for persons in isolated persons with hindered access)

The executed analysis allowed a detailed definition of receiver groups, at which surveys have been addressed. The objective of this kind of survey was to allow compiling opinions concerning current needs related to access to new technologies, such as UAVs. This was a determinant during the MOBNET system designing process. It also enabled the establishment of a data base of stakeholders in this solution thanks to describing project assumptions.

Key issues about which the respondents were asked included the following:

- Personal and contact data (education, professional experience, nationality)
- Potential use of the MOBNET system
- Required accuracy of the location of the victim, number of concurrently located cell phones
- System operating time (on internal power source)
- System operating conditions (threshold, temperature, humidity, wind speed, precipitation, etc.)
- Involvement of rescuers (number of persons who could handle the system in typical conditions, system weight, transport options)
- Requirements concerning the user interface (display of specific data, visualisation, etc.)

Thanks to such structuring of the survey, its results allowed making a detailed delimitation of rules for system functioning. In addition the received responses served also as guidelines for designing the user interface.

4. Survey outcomes

Result of the survey allowed obtaining an image of the optimum solution—a system which would contribute to optimising search actions, in which use is made of a combination of the satellite positioning system (GPS) and cellular technology (DCT).

A total of approximately 300 surveys have been sent out to selected target groups. Sixty-seven responses were received from respondents from four member states of the European Union. Almost a half of them were firemen. Further 15% were border guards. The remaining professions of the respondents included members of search and rescue groups, policemen and soldiers. A median in the set containing the number of years of the respondents’ professional experience equalled to 19 years.

Below presented were selected results of the survey.

Figure 3 shows that the respondents did not care too much about the relatively low system inaccuracy. This arose from the nature of typical search and rescue actions. Firemen are, for example, forced to remove heavy structural elements, and so the indication of an area where a person is localised usually appears to sufficient.

It may naturally be expected that the longer the time of using of the system, the better. Taking into account the obtained responses, it may be assumed that an operating time of a few dozen minutes between subsequent charging and replacement of battery would be optimum. Furthermore, taking into account the nature of system operation, all signals would be detected almost in real time, which allows finishing the flight and turning over data to the commander of search actions. Representatives of other services, in particular of border guards, specified much longer times, which are the result of the system used that is most typical for them, namely, flights over the border area.

A question of particular importance for the project concerned information indispensable for UAV operator. Respondents specified in the first place the GPS position, preview of map of the land over the drone is moving, the flight trajectory and the video transmission. As regards categories included in the “other” section, they included among others wind speed, starting position of the UAV, number of detected signals, flight time and ambient temperature.

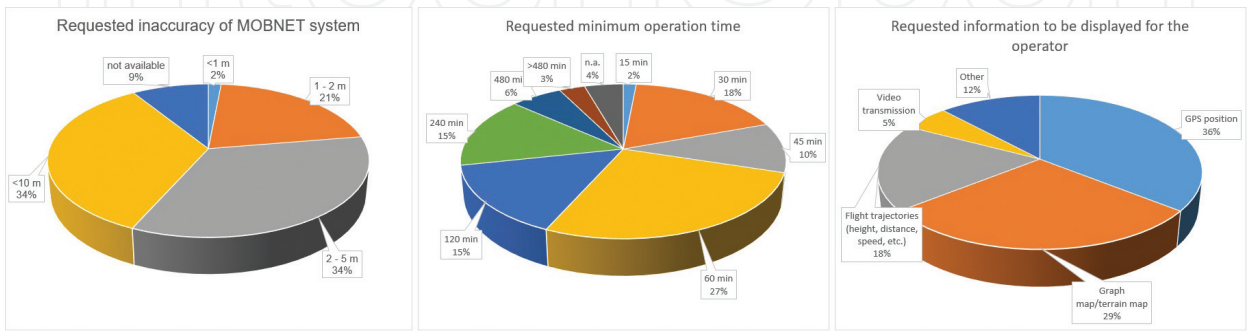


Figure 3. Selected results of the conducted survey: system inaccuracy (to the left), minimum operating time (centre) and components of user interface (to the right).

As regards the execution of actions, the respondents were asked for feedback concerning issues related to system operation in real time. The obtained responses have shown that the system should be capable of searching ca. 10,000 m² during a 30-minute flight. It should be operating within the range of ambient temperature from -20 to $+50^{\circ}\text{C}$, at a wind speed of even 10 m/s. Furthermore, the distance of the aerial vehicle from the operator should, in the opinion of respondents, be ca. 550 m horizontally and ca. 300 m vertically.

The majority of respondents were of the opinion that it would be possible to use their own operator (81%), while 66% of them saw the possibility of involving at least two rescuers in the operation of the system (during the execution of their typical activities).

A question of particular importance was one concerning the number of concurrently detected signals (mobile phones). In the opinion of almost 50% of respondents, it was sufficient to detect up to 10 signals during one mission. One third of the respondents marked the necessity of detecting up to 100 telephones simultaneously. Three respondents were convinced that the system should be capable of detecting more than 100 signals, yet this applies to the proposed system application during mass events (for needs of registration and potential control of the presence of a given person among participants of the event).

5. Technical approach

5.1. The principles of operations of UAV

Unmanned aerial vehicles (UAVs) may be used to execute a wide spectrum of tasks, which helps reduce the risk that may take place during their implementation by manned aerial vehicles and potentially reduce costs of their usage. Basic structural types of UAVs include unmanned airplane, unmanned airplane with a possibility of rotor rotations, unmanned helicopter and gyroplanes (multicopter). Gyroplanes are capable of changing the flight direction in a brief time and have the capacity of zero-distance start and landing and precise spot hovering over the scene of an incident. They are also adapted to operating in very confined spaces.

The advantage of the drones is that it is no longer necessary for a person to be directly in the helicopter, but he may control it personally from a safe place. This also implies savings of means connected with production, operation and training, even though handling of such equipment also requires outlays connected with obtaining the relevant licences. On the other hand, one of the possible hazards is inexperienced operators unable to use them in a safe way.

In the context of finding victims, drones are not the only available solution. The methodology analysed in this chapter is based on measurements of the propagation force of radio waves that are emitted by cellular phones. An important assumption is that victims being rescued remain in the vicinity of their phones. The strength of signal coming from persons inside buildings is subject to nonlinear disturbances, which may cause significant deformations of the obtained estimated locations of victims. Alternative traditional methods of finding victims comprise search made by man or the usage of snuff dogs.

Drones are the perfect choice for use on contaminated areas, locations of difficult access or ones that pose a hazard for people. This may be illustrated by the example of the problem of cleaning up the contaminated nuclear power plant in Fukushima, even though in this particular case not drones, but unmanned robots were used. This is a scenario in which human abilities cannot be used directly. On the other hand, in such difficult conditions (given temperature and radiation), already 10 robots have been lost during the execution of works on this location (state as on March 11, 2017).

Thanks to their dimensions, drones are also less susceptible to changing weather conditions (this is determined by the type of machine), which makes them easier to use. They may be used during extreme weather conditions, as well as in locations with difficult access, eliminating a hazard for the pilot's health and life. Another advantage is the fact that they may approach facilities or the ground more closely, which allows more accurate and easier diagnosis of potential damage. The deployment of this solution allows increasing the repeatability and accuracy of control and also significantly reduces the operation time.

5.2. Proposed solution: technical aspects

The GPS system informs of the situation of UAV in the air and its flight direction. Thanks to satellite navigation, the installed GPS system finds the accurate position of UAV over the land surface. This system has been provided in the fuselage. In addition, UAV may be equipped with high-quality cameras that record images in real time and allow the location of a potential victim. High-resolution video recorders are not the only advantages offered by the drones. They are also furnished with thermal vision cameras that enable archiving images and recording thermal radiation emitted by almost each physical body. This allows them to operate during the night and in difficult weather conditions.

5.3. The concept of MOBNET

MOBNET has been established to localise victims during natural disasters and extraordinary circumstances, such as earthquakes, hurricanes or snow blizzards. It may also assist rescue services in such activities as the search and finding of missing persons. To ensure precise localisation, the device is compatible with the European satellite navigation system EGNSS, which is characterised by a small margin of error (ca. 1 m). Cellular phones emit a signal in the form of data at regular intervals, so the use of the DCT technology in the device will allow the detection and identification of victims during rescue actions. In the prototype being in the phase of development, the EGNSS and DCT technologies are fully synchronised to assure the most accurate finding possible. During works over the device, an effective and infallible communication link will be developed between unmanned aerial vehicles (UAV) and the terrestrial station. The objective is to obtain a data link which would enable incessant communication of commands between elements. The new system will allow making use of European global satellite navigation systems (EGNSS) including its earlier applications, such as Galileo, and EGNOS, and also digital cellular technologies (DCT), which is to enable the localisation of victims in situations in which access to them is hindered, dangerous or impossible. **Figure 4** presents an operating diagram of the MOBNET system.

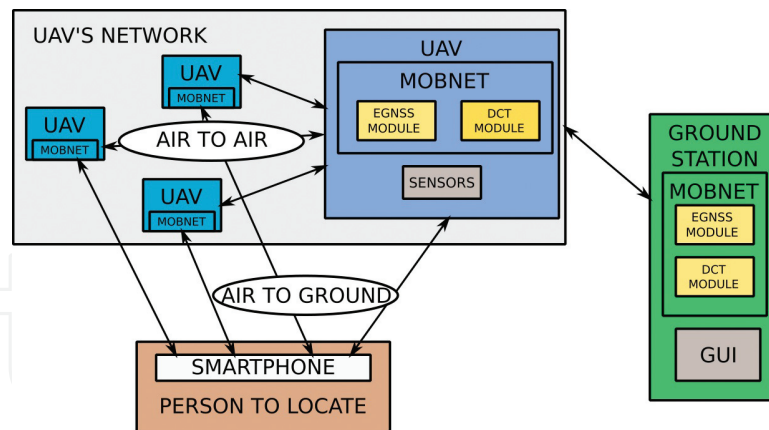


Figure 4. Operating concept of the MOBNET system [7].

6. Conclusions

Actions of search and rescue groups are challenging for many reasons. Above all those actions are carried out as a rule on an unknown area, in many cases abroad, and the terrain conditions tend to be complex. Given restrictions connected with personnel, new methods and technologies are being sought which may significantly affect the effectiveness of those actions. Enhancing the effectiveness of activities of search and rescue groups is strictly connected with performing a quick and precise determination of the size of the hazard zone and localisation of persons at risk. Consequently the MOBNET project, which makes use of a technology based on the system that localises signals of cellular telephone in a way which would eliminate any inconveniences connected with difficult terrain conditions, concurrently allowing obtaining a picture of the incident scene from above, seems to be a very good solution enhancing the effectiveness of actions performed by search and rescue groups.

Typical solutions for search and rescue actions comprise the usage of specially trained dogs, inspection cameras, geophones, etc. At a time of dynamic technological progress, new possibilities keep appearing. Innovative implementation of both the EGNSS technology and DCT opens new possibilities to public services. The identification of signals emitted by cellular phones naturally cannot replace proven traditional methods yet may to a large extent contribute to improving the effectiveness of the search actions. In particular in the case of vast areas, the MOBNET system may indicate the most important zones where resources and means would be sent as priority. This is due to the fact that in such situations, even mere minutes can determine the survival of the victims.

Under the MOBNET programme, a ready solution was offered for public services. The system has been extensively tested with view to integration of particular components. In February 2018, a demo meeting is to take place, during which detailed results of the project are to be presented. Tests in simulated conditions comprise scenarios of incidents typical for search and rescue groups.

By the time this manuscript was being prepared, the integration test took place. The results of in-field testing were satisfactory. The performance of MOBNET system fulfilled all prerequisites at the beginning of the project. It is able to localise cell phones basing on an innovative approach connecting DCT and EGNSS technologies.

The conducted survey allowed the identification of structural limitations required by final users. The diversity of professions of the respondents also allowed obtaining suggestions concerning further development of the system and potential areas where the ready MOBNET system may be deployed.

It is important to notice that the system might be implemented not only in fire service. As the survey outcomes showed, there are many different potential fields of application. Other public services might use the MOBNET system, e.g. police might log the phones active in particular area, and border police might track the violation of border integrity. It might be used to control the areas of limited access for unauthorised personnel.

The popularity of smartphone usage is constantly growing. Most of us carry the device with ourselves during the whole day. Therefore it is highly probable that the localization of our cell phone will be equal with the localization of ourselves. And that is particularly identified gap that might be filled with the MOBNET system, in purpose to improve the effectiveness of search and rescue operations.

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